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Conceptual Mechanical Design of a CsI Calorimeter for GLAST

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Abstract

This report briefly describes a conceptual mechanical design developed for the hodoscopic CsI calorimeter envisioned for the Gamma Ray Large Area Telescope (GLAST) project. The Calorimeter is a stack of scintillating Cesium Iodine logs, in 8 layer with alternating orientations. The work described here consists in the development of a mechanical concept for a stacked assembly capable of surviving the mechanical and thermal environment of a rocket launch. Issues of compactness, ease of assembly, and electronic packaging are also considered. This work was performed under contract #N00173-98-P-2007 with the Naval Research Laboratory (NRL), under the supervision of Dr Neil Johnson.

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OI	June 29, 1998	E. Ponslet, F. Biehl, W. O. Miller, R. Smith	Initial release.
A	April 12, 2000	E. Ponslet	Updated document number, added Revision log

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1. Hodoscopic CsI Calorimeter – General Description

The calorimeter[1,2] proposed by NRL for the Gamma Ray Large Area Telescope (GLAST) consists of a stack of 80 Cesium Iodine (CsI) logs, each approximately 25x30x310mm, arranged in ten layers of 8 logs each. Each layer is rotated 90 degrees relative to its neighbors to form an XY array. Each log measures the energy deposited into it by incoming particles and the approximate location of the impact along the length of the log. This, combined with the multi-layer design, provides 3-dimensional location information in addition to the amount of energy deposited.

To contain and measure the light induced in the CsI, each log is wrapped with a multi-layer light shield and instrumented with PIN photodiodes at both ends. An array of electronic circuits conditions the signals from the photodiodes. Those circuits are arranged on PCB boards mounted all around the stack and inside the outer envelope of the calorimeter.

The calorimeter is intended to be a mechanically independent subsystem of GLAST; this allows for complete testing and characterization of each calorimeter, prior to integration in the full-up instrument.

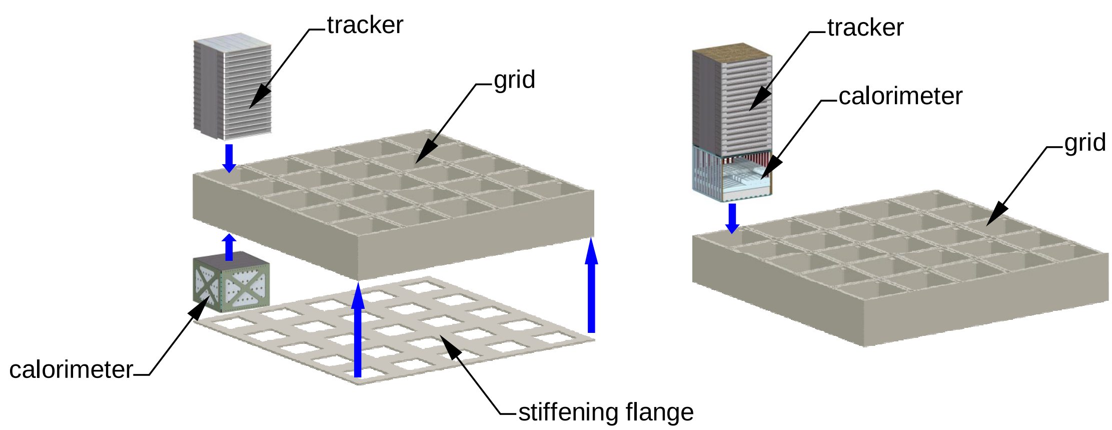

Figure 1: two options for the overall configuration of the grid, tracker, and calorimeter in the GLAST instrument; left hand figure shows calorimeter inside grid option; at right the calorimeter & tracker assemblies are mounted above the grid.

The complete baseline GLAST instrument contains an array of 5x5=25 calorimeters, mounted either on top or inside the structural "strong-back" of the instrument (grid) as illustrated in Fig. 1. Because at the time of this study one or the other mounting options had not been selected, the calorimeter is designed to be compatible with both. The calorimeter-inside-the-grid option is the least demanding for the calorimeter design because of the added external support provided by the grid and because the trackers can be mounted directly to the grid. In the alternate option, the calorimeter mounts on top of the grid, with the tracker mounted at the top of the calorimeter. In that case, the dimensional accuracy and stability of the calorimeter outer structure becomes critical for achieving proper alignment of the tracker.

2. Preliminary Mechanical & Thermal Requirements

GLAST will be a satellite based experiment and as such, all of its components must be designed to survive the harsh mechanical environment of the launch. The envisioned launch vehicle for GLAST is a DELTA II, 2-stage rocket[3].

Rough design load factors of +10g and -2g in the launch direction and +/- 5 g's in the transverse plane were chosen for this study, loosely based on DELTA II specifications[3]. The launch environment also involves substantial vibrations (both from acoustic coupling and direct mechanical transmission). This initial design work considers a random vibration input at the base of the calorimeter[5] as specified in Fig. 2; acoustic inputs were not considered.

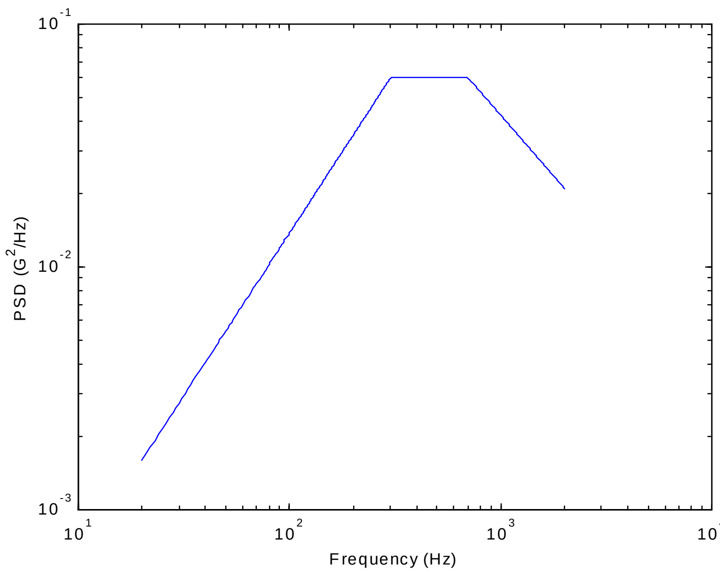

Figure 2: random vibration spectrum used in this study[5]; overall acceleration level is 8.7 g RMS.

During assembly, testing, shipping, installation and launch, the calorimeter will likely be subject to temperature variations. Cesium iodine has a very large coefficient of thermal expansion (50 ppm/ºC) so that, even moderate temperature variations lead to substantial dimensional fluctuations of the CsI logs. This together with the requirement for a dimensionally stable outer structure imply that some compliance must be built into the mechanical design of the stack to accommodate thermal expansions of the logs without unreasonable stresses. A conservative temperature range of –10 to + 50ºC (60 ºC swing) was adopted for this conceptual design phase. The assembly temperature is assumed to be around 20ºC.

Static load factor	axial (launch direction)	+10 g (down), -2 g (up)
	transverse	+/- 5 g
Vibration	random only	8.7 g RMS, see Fig. 2, axial and transverse
Temperature Range	assembly, testing, shipping,...	-10ºC to 50ºC, assembly temp = 20ºC

Table 1: summary of tentative mechanical and thermal design requirements used in this study of the GLAST calorimeter.

Because it is critical to maximize CsI coverage in the GLAST instrument, the design should also minimize the amount of physical space occupied around the CsI logs, either for required clearances between components or for those components themselves. In addition, all materials (structural or otherwise) used in the design should have the smallest possible interaction with gamma rays and secondary particles. This can be achieved by minimizing the total volume or mass of material involved and whenever possible giving preference to materials with long radiation lengths (beryllium, carbon composites, aluminum for example).

As mentioned above, the CsI logs are individually wrapped in optically tight materials. The current, demonstrated technology for this wrapping is a layer of a special quality of Teflon tape, followed by an outer layer of aluminized Mylar foil. The wrapped foils are held in place with tape. The presence of these wraps complicates the design of a mechanical holding concept: slippage of the logs inside the wraps, wrinkling or other damage to the wrapping itself, as well as the imperfect outer surface and the tendency to build pressure points must all be considered.

Cesium Iodine is not a very tough material; its surface is easily scratched or damaged by excessive pressure, and it reputed to creep measurably under large mechanical loads. These characteristics must also be taken into account when designing mechanical restraints for the logs. In particular, the issue of creep is particularly critical with the proposed design (described in section 4). Unfortunately, because very little data is available in the literature, that aspect was not covered in this initial study. Testing will be performed before the design can be further developed.

Whatever mechanical concept is used to hold the logs together, it should also be reasonably easy to disassemble so that a defective log can be removed and replaced if required.

3. Earlier Design Concept – Critical Review

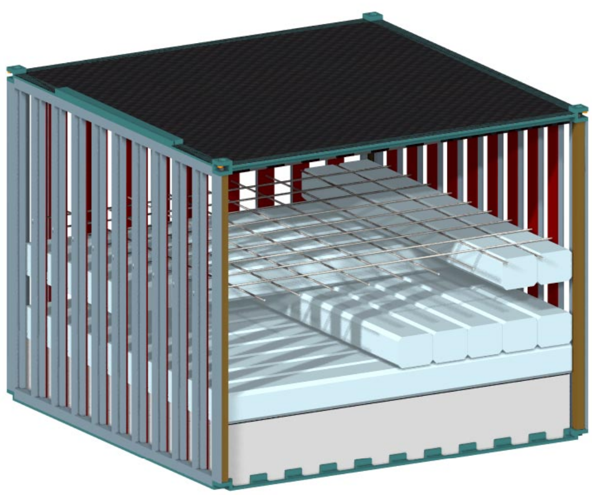

Figure 3: the baseline “jail-bar” calorimeter design concept.

When HYTEC was asked to look at the mechanical design of the calorimeter, a mechanical packaging concept had already been proposed by NRL; that concept will be referred to as the *jail-bar design*[1,2] in the rest of this document. A brief description and critique of that concept is useful in that it provides a background to the work performed by HYTEC, provides an opportunity to discuss some critical design issues, and gives insight into the motivations for the design concept that is proposed in Section 4.

The jail bar design is pictured in Fig. 3. The wrapped crystals are stacked against each other to form a bloc about 31 by 31 by 20 cm. The total mass of CsI in the stack is about 80 kg. A stiff outer cage of carbon fiber composites is built around the stack and provides compressive preload to the stack in 3 directions through a number of 1mm thick rubber pads, which are also intended to “absorb” the thermal expansion differential between the logs and the outer structure. Because carbon fiber has an almost zero coefficient of thermal expansion), the rubber must essentially absorb the full expansion of the CsI logs.

The outer cage consists of bottom an top sandwich panels connected together by a large number of carbon fiber I-beams which must be stiff enough to provide the lateral preload without substantial bending. To help support those beams against bending, tie rods may run between the CsI logs from one side of the stack to the other; this would require chamfering the edges of the logs to provide space for those rods. The spaces between and outside of those beams are used to house 32 separate printed circuit boards that collect and condition the signals from the PIN diodes. The complete assembly then receives an outer wall of protective, optical and EMI shielding.

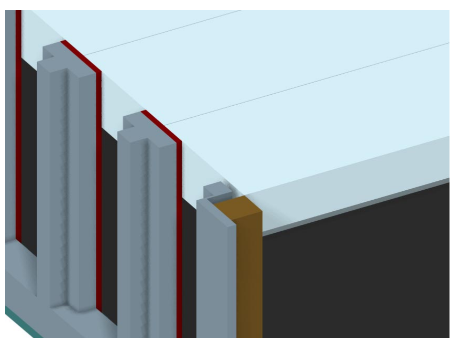

Figure 4: “jail-bar” design; arrangement of components around CsI logs; assuming 1 mm outer walls (not shown), the distance from the CsI to the outer surface of the calorimeter is 10 mm (for comparison with Fig. 9, note that the space allocated for electronic components is only about 2.5mm in this design, compared to 4 mm in the design of Fig. 9).

The following observations can be made about the jail bar design:

1. the choice to use lateral preload on the stack (in addition to vertical preload) leads to a fairly massive structure for the side walls (i.e. the I-beams). This leads to a relatively large dead space around the crystals. In the event where tie rods would be used, the crystals would have to be chamfered and the assembly of the stack becomes significantly more complicated.
2. the presence of the I-beams around the sides and the need to minimize lateral dead space leads to the use of 32 separate circuit boards (8 per side) instead of 4 (1 per

side) larger, continuous circuit boards. Continuous boards would offer advantages of reducing the cabling requirements and the number of connections, simplifying the mechanical assembly, and allowing layer-level preprocessing activities.

3. the launch loads and vibrations will require substantial pressure applied on the crystals to avoid rattling and slippage. Without any compliance between the logs in the pressure direction, it is likely that pressure points will develop (where tape is used to hold the wraps for example) and cause damage to the wrapping materials or the logs themselves. Also, because the outer dimensions of the logs and the thickness of wrapping material are not controlled very tightly, it is unlikely that every crystal in the stack will see the same amount of pressure. In fact, it is possible that single crystals could end up being loose in the vertical direction.
4. the I-beams provide the preload on the stack but also directly control the outer dimensions of the calorimeter (the parallelism of the top and bottom panels for example). With the amount of load imparted into those beams, a precise, removable, fastener-based attachment to the bottom and top panels would be difficult to design.
5. Under the assumed 60ºC temperature swing, the length of a CsI log changes by 50 ppm/ºC × 60ºC × 310 mm = 0.93 mm. Two rubber pads, 1 mm thick each, absorbing this change would see strain variations in excess of 45%, in addition to whatever compressive load is required at the lower temperatures; good practice design values for compressive rubber parts range from 10 to 15%[4].

4. Proposed Mechanical Concept

4.1 Design Philosophy

We have tried to develop a mechanical concept that addresses some of the issues listed in Section 3 in relation to the jail bar design. In particular:

1. because dead space is much more critical around the periphery of the calorimeter than at its top or bottom, a unidirectional compression cell, with the compressive pressure applied by the top and bottom panels only is likely to improve coverage. The lateral restraint of the logs in such a design would be provided by friction only. The heavy side structure of the jail bar design can be replaced by a much less intrusive set of tension members. Those tension members provide the bulk of the compressive load on the stack; the rigidity and dimensional stability of the assembly can then be provided by the outer walls (which are needed anyway for protection and shielding).
2. a less intrusive side structure would potentially leave sufficient space for continuous, full coverage circuit boards; this considerably simplifies the mechanical assembly (part count) and the design of the electronic processing schemes.
3. distributing the necessary compliance (for tolerance to thermal expansion inside a stiff and stable structure) between the layers of logs (and therefore in the direction of compression in a unidirectional design) has a number of advantages: it spreads the pre-compression better on the surface of and between the logs, is more tolerant to irregular log surfaces and dimensional tolerances, and – in a unidirectional compressive design – provides space for increased total rubber thickness without impacting lateral coverage.

4. achieving a design that can be completely disassembled with the minimum amount of effort and component replacement is a primary goal.
5. in view of the special requirements for space applications, a conservative approach to the design in general and the rubber pads in particular must be followed.

4.2 Description

The unidirectional compression stack design concept proposed by HYTEC is shown in Fig. 5. The concept is based on unidirectional (vertical) compression of a stack of CsI log layers and compliant layers. The compression pressure is applied by two sandwich panels at the bottom and top of the stack, tied together by 36 tension members (cables or rods, see Section 4.3.5 below). These tension members are mounted very near the ends of the CsI logs and occupy little space since they do not have to resist any transverse loads. Also, since they fit in the space between adjacent PIN diodes (Fig 6), they do not impact the amount of dead space around the logs.

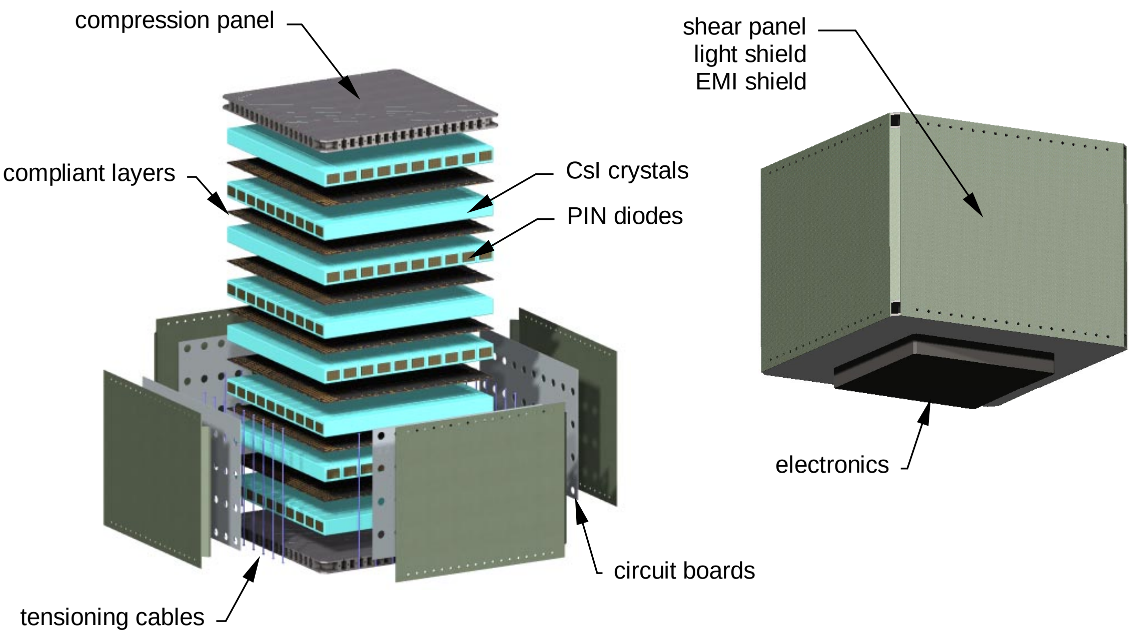

Figure 5: proposed mechanical design form the GLAST calorimeter.

Four single piece PC boards are then mounted outside the compressed stack. Wiring to the PIN diodes is done through a series of access holes, using compliant wires or flexible circuits. After full testing, the entire assembly is covered with 1mm thick carbon fiber panels that provide additional stiffness and dimensional stability. These panels can also serve as optical and EMI shields. A number of small soft foam pads between the outside of the PC boards and the inside of the side panels may help reduce acoustic response. The corners of the calorimeters are chamfered to provide more space for structural materials and fasteners in the grid (required only for calorimeter-inside-grid option).

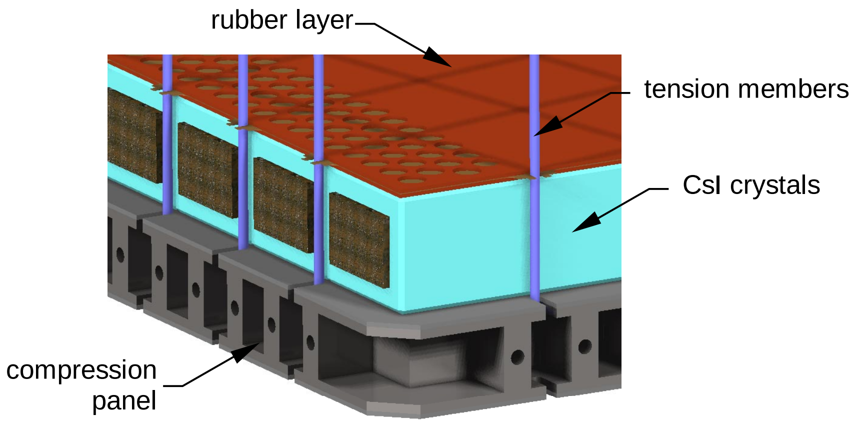

Figure 6: bottom compression panel with one layer of crystals and tension members.

The compliant layers (Fig. 7) are made of two perforated rubber sheets "sandwiching" a thin carbon fiber membrane that limits transverse deformations, provides guiding supports for the tension members (reducing the amplitude of violin modes during launch), and partial support of the PC boards (limiting drum deformations during launch). The rubber sheets could optionally be attached to the carbon membrane with an adhesive (to simplify assembly) or simply stacked and held in place by friction.

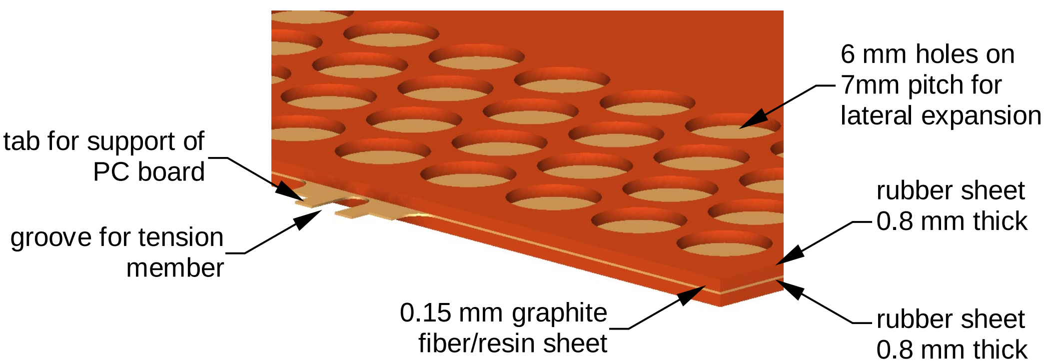

Figure 7: compliant layer design.

When compressed, the rubber layers conform to the somewhat irregular outer surface of the logs and should produce a relatively uniform pressure distribution on the logs. The amount of compression on the stack is designed to generate enough friction between stack components that no other lateral restraint mechanism is required (see section 4.3.3 below). The rubber layers also accommodate the large thermal expansion of the CsI logs (the outer structure is a dimensionally stable box; carbon composites have a very small coefficient of thermal expansion).

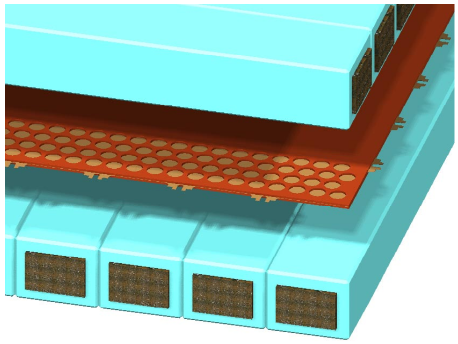

Figure 8: stacking of CsI logs and compliant layers.

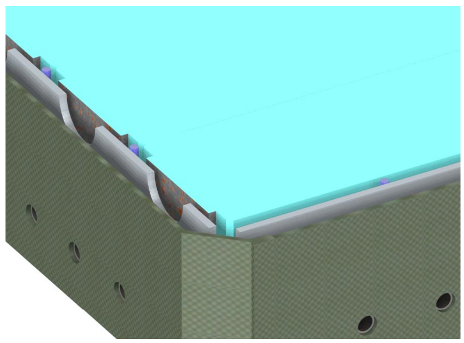

Figure 9: arrangement of components around CsI logs; the distance from the edge of the logs to the outer surface of the walls is 9 mm.

The signals from the 4 PC boards are collected in a calorimeter electronic module, mounted directly underneath the bottom sandwich panel. Wiring to that module is achieved with flexible printed circuits, routed through slots in the outer edge of the compression panel close-outs, inside of the side panels. The design also allows for optional side-to-side flexible connections between adjacent PC boards. A chained configuration where all 4 side PC boards are connected together via flexible circuits wrapped around the corners of the stack may be attractive.

4.3 Rough Sizing

4.3.1 General Calculations

Each CsI log measures approximately 311mm x 31mm x 25 mm; the density of CsI is 4.35 g/cm^3; with 80 logs per calorimeter, the mass of CsI is approximately 85 kg. With a downward vertical acceleration of 10 g, the total inertial force to be reacted at the bottom of the calorimeter is 8350 N, corresponding to a pressure of about 86 kPa.

4.3.2 Total Thickness of rubber in Stack

With +/- 30ºC temperature swings from assembly temperature, the total height of CsI in the stack varies by about +/- 0.47 mm. We assume that the initial compressive strain in the rubber layers is about 10% (a usual design value for rubber compression pads[4]). Allowing an additional +/- 4% strain from thermal expansion effects (i.e. the stack preload would drop to 60% of its assembly value at the low end of the temperature range), we find that the total thickness of rubber in the stack should be about 0.47 mm / 4% = 12 mm. With 16 layers in the stack, this leads to a minimum rubber layer thickness of 0.75mm.

4.3.3 Amount of preload required at assembly

The assembly is preloaded in vertical compression by the tension members and the top and bottom panels. During launch, the downward acceleration increases the preload against the bottom panel and decreases it at the top panel. Assuming top to bottom symmetry, the top layer of rubber unloads by ½ of 8350 N, while the bottom layer overloads by the same amount.

To insure the integrity of the assembly, the top layer must maintain enough pressure to hold the logs in place against a lateral acceleration of 5 g (accounting for transverse vibrations). Again assuming symmetry, the transverse load imparted to the upper layer of rubber is about 2090 N. The minimum coefficient of friction anywhere in the stack is assumed to be 1/3 (between CsI and wrap or between successive layers of wrapping).

With the launch temperature not defined, we take the very conservative assumption that this temperature could be at the low end of the design range (i.e. 30ºC below assembly temperature). As shown above, at that temperature, the preload drops to 60% of its assembly value because of the thermal contraction of the CsI logs.

Putting it all together, the initial assembly preload *P* (in N) on the stack, must be such that

$$\left(60\%P - \frac{8350}{2}\right)\frac{1}{3} \geq 2090 \ , \tag{1}$$

or $P \geq 17.4\ \mathrm{kN}$.

4.3.4 Rubber Layers

We already know that each layer of compliant material should be about 0.75mm thick and should generate about 17.4 kN of compressive load at 10% compressive strain. The compressive stiffness of a layer should then be around 232 N/µm.

Rubber sheet material is widely available in a thickness of 1/32”=0.8 mm. Because of the very large aspect ratio of the layers (311mm square by 0.8mm thick) and the almost incompressible behavior of rubbers, the layers must be designed to allow lateral expansion of the rubber. We decided to consider sheets perforated with a honeycomb pattern of circular holes (easy to manufacture for prototype testing).

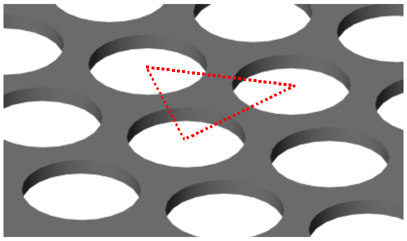

Figure 10: perforated rubber sheet; a “unit cell” is shown in red.

The entire layer can then be analyzed by considering a single unit cell (see Fig. 10). Semi-empirical design techniques[4] give estimates of the compressive stiffness of such cell from the ratio of stressed area to free area available for lateral expansion. Trial and error leads to an array of 6 mm diameter holes, spaced every 7 mm in 3 directions (0/60/120 degrees). The estimated axial and shear stiffnesses are 215 N/μm and 19.6 N/μm, respectively. The shear deformation in the bottom and top layers, under 5 g transverse acceleration would then be a reasonable 100μm (see Section 4.4.4 below for a more detailed deflection analysis).

4.3.5 Tension Members

With a total compressive force of 17.4 kN, and a 40% overload from thermal expansion at +30ºC over assembly temperature, the maximum total load to be reacted by the tension member amounts to about 24.5 kN. The proposed design includes 9 tension members on each of 4 sides of the calorimeter, for a total of 36 members. This puts the maximum tension load on each member to about 680 N (150 lbf). Using a 60% safety margin to ultimate strength[5], and assuming a circular cross-section, the required diameter of those members would be about 1.0 mm for a braided Kevlar cable or a unidirectional graphite/epoxy rod, 1.8 mm for a high strength aluminum rod, or 1.6 mm for a beryllium rod.

4.3.6 Top and Bottom Compression Panels

The total compression force to be applied (at the high end of the temperature range and with a downward acceleration of 10 g) is about 24.5+4.2=29.7 kN (see Section 4.3.4 above). The panels should be stiff enough to provide a somewhat uniform pressure distribution on the stack. Assuming uniform pressure, the panel must resist 262 kPa. From rough calculations it quickly appears that keeping the center deflection of the panels to a fraction of the thickness of rubber layer (i.e. in the 10 μm range) is not practical (panel thickness would have to exceed 3 inches). A possible alternative is to manufacture the panels so that the face sheet that contacts the rubber layer has a lens shape with the center thickness slightly larger than the edge thickness. This is easily achieved with composite face sheets by simply increasing the number of plies toward the center of the sheet.

With this in mind, a sandwich panel with a 17 mm thick core (graphite honeycomb), and 1.5 mm thick quasi-isotropic graphite/epoxy face sheets is considered. Under uniform pressure of 262 kPa, that panel, simply supported at the edges by the tension members, would deflect by about 140 microns at its center. The thickness of the face sheet in contact with the rubber layer would then vary from 1.50 mm at the edges to around 1.64 mm at the center. The top panel would represent about 1.3 % of a radiation length.

4.4 Analytical Simulations

This study being at a conceptual design stage, only a few key aspects were subject to modeling and simulation. These aspects include a closer look at the compressive and shear compliance of the rubber layers, modes and natural frequencies of the calorimeter assembly, the effect of the side walls, and the response amplitudes to both static and random vibration loads. These studies are summarized below.

4.4.1 Rubber Spacer Compliance

To verify sizing calculations of axial and shear stiffness, FEM models of a unit cell of perforated rubber sheet, 0.8mm thick, with 6 mm holes every 7 mm in a 0/60/120 degree layout were created. Non-linear stress-strain curves were calculated and the stiffnesses in axial and shear directions were evaluated, at a 10% compressive pre-strain. The results are summarized in Fig. 11 and show excellent agreement with the estimated values from Section 4.3.4.

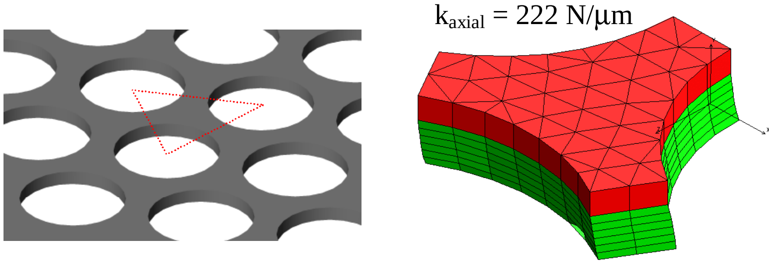

Figure 11: FEM model for compressive and shear stiffness of compliant layer; stiffness values are for a complete 31 by 31 cm sheet.

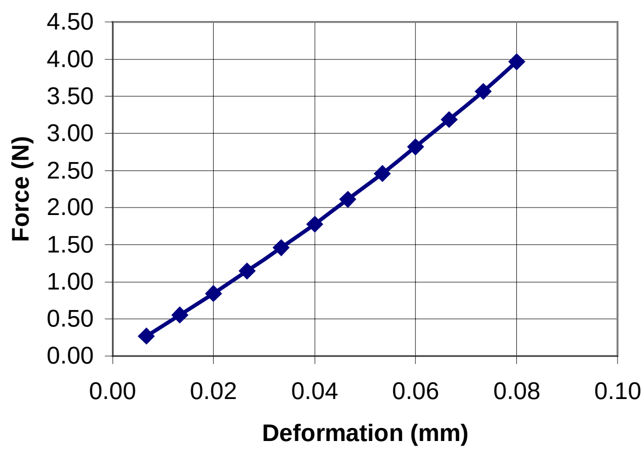

Figure 12: force-deflection in compression from FEM of unit cell of rubber layer; stiffening is due to bulging of the rubber.

4.4.2 Elastic Model of Calorimeter Assembly

An approximate elastic model of the calorimeter was built using an in-house lumped parameter code. The model consists of an assembly of rigid masses and 3 dimensional springs with damping. This very simplified model assumes that every layer of logs behaves like a rigid body that can move relative to the other layers by deflecting the rubber layers. The top and bottom panels are assumed infinitely stiff. The compliance of the outer shear panels is modeled (1 mm thick, quasi-isotropic carbon/epoxy composite).

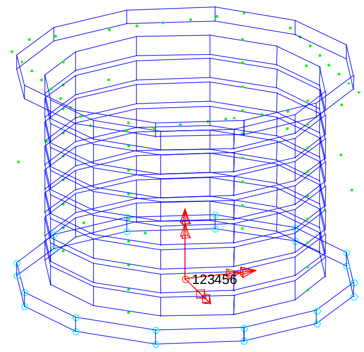

Figure 13: lumped parameter elasto-dynamic model of calorimeter assembly (54 degrees of freedom); mass elements are shown as blue cylinders and spring elements as green dots.

Two attachment configurations were considered:
1. the calorimeter is attached at the top of the grid; the top panel is free.
2. the calorimeter is embedded inside grid; top panel is held in place by the grid.

Case #1 leads to deflections of the upper panel relative to the base, from shear deformations of the side panels. In case #2, all deformations consist of displacements of the CsI layers inside the calorimeter "box".

4.4.3 Natural Modes and Frequencies

The lumped parameter model is first used to evaluate natural modes and frequencies of the assembly. The results are summarized in Fig. 14. The first two modes involve shear deformations between layers and – when the top of the calorimeter is not supported in the grid – some shear deformations of the outer panels. The third mode could be described as twisting around the vertical axis of the calorimeter. Note that the loss factor in the rubber layers was conservatively assumed to be about 15% (Q=6.7). The actual value depends on the final material selection and is beyond the scope of this study.

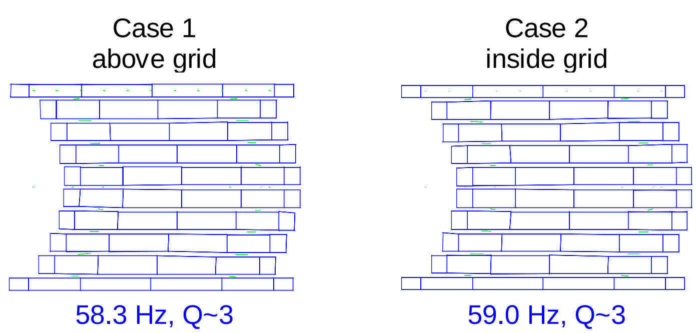

Figure 14: first natural mode predicted by the lumped parameter model; left side is for case #1 (calorimeter on top of a grid), right side shows case #2 (calorimeter inside grid).

4.4.4 Static Response

The same model is used to calculate static deflections under the design load factors. Results are shown in Fig. 15 for both cases. The transverse motions of the CsI logs are less than 450µm; the clearance to the PCB board is currently set to 1 mm.

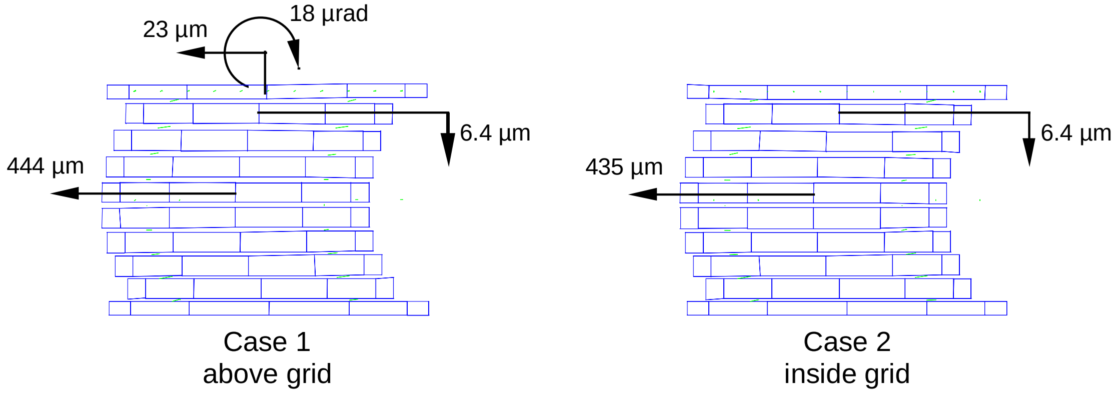

Figure 15: calculated static deflections at 10 g vertical and 5 g transverse load factors; left side is for case #1 (calorimeter on top of a grid), right side shows case #2 (calorimeter inside grid).

4.4.5 Random Vibration Response

The random vibration response can be estimated by hand by assuming that most of the amplitude comes from the first mode of vibration. The calorimeter then behaves like a single degree of freedom system excited by base motion, and the response is a narrow-band process whose standard deviation is easily evaluated. The statistics of peak responses follows a Rayleigh distribution and the level not exceeded by 95% of the peaks can be calculated using the error function (that level is roughly equal to 2 times the RMS deflection). Modal participation factors are used to extrapolate to the deflections of a particular layer in the stack.

The standard deviation of the response can also be calculated directly by numerical integration of the PSD (power spectral density) of the response obtained from numerical simulations using the lumped parameter models.

Values were obtained from both methods and were in excellent agreement with each other. For case #1, the peak deflections (for 95% of the cycles) are less than 14 µm at the top compression panel and less than 260 µm for the middle layers of CsI logs. Case #2 shows a peak deflection of the middle layers of CsI of less than 255 µm.

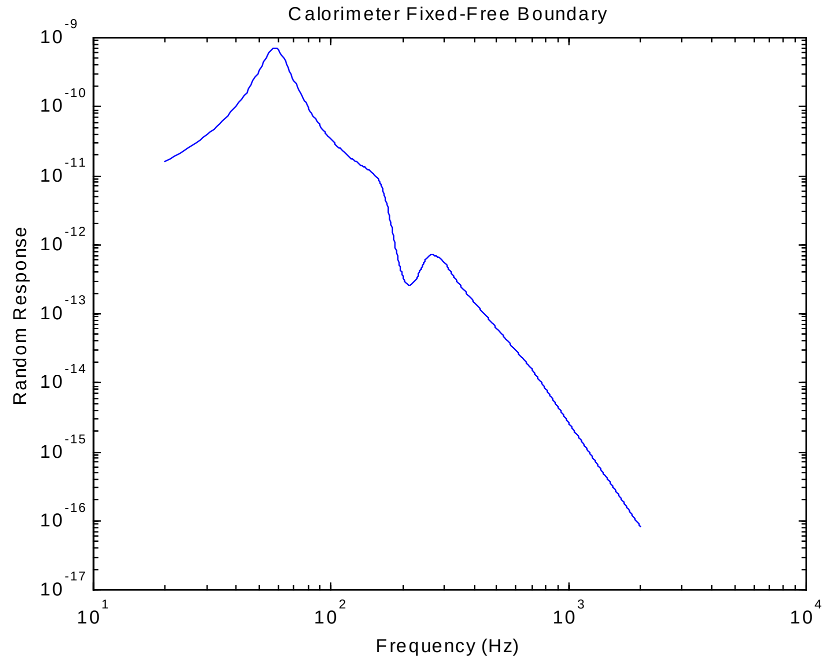

Figure 16: case 1: calorimeter above grid; amplitude spectral density (m^2/Hz) of lateral deflection of middle layer of CsI logs in response to base motion defined in Fig. 2; case 2 is almost identical.

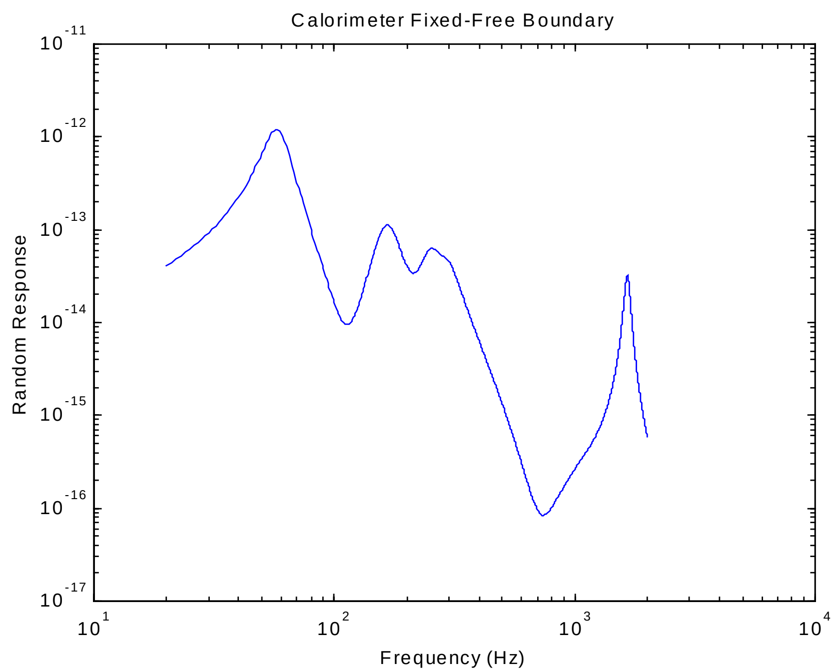

Figure 17: case 1: calorimeter above grid; amplitude spectral density (m^2/Hz) of lateral deflection of top compression panel in response to base motion defined in Fig. 2.

5. Open Issues and Recommendations for Future Work

The study described in this report is conceptual; substantial design and analysis effort would be required to evolve the design into flight-ready hardware. What follows is a non-exhaustive list of issues that particularly require further attention.

5.1.1 Validation of Unidirectional Compression Cell Concept

The proposed calorimeter design concept relies on unidirectional compression of a stack of CsI logs and compliant rubber layers. Lateral restraint is left top friction and shear stiffness of the stack only. This validity of this concept must be demonstrated through systematic testing of the ideas involved (see Section 6). In particular, the following issues should be examined:

- slippage and rubbing problems, in particular between the CsI and the wrapping material under transverse acceleration and vibrations; note that improvements in the wrapping technology or the development of alternative shielding techniques may provide some help in this area.
- flowing of CsI under constant pressure: cesium iodine is know to have measurable creep under load. Very little data is available however, so tests will be required.
- long term effects of pressure on optical qualities of logs

5.1.2 Preliminary Design Choices

These are a number of the detailed design and material selection issues that must be examined:

- material for rubber layers (space qualified, low outgassing) and venting (trapped air pockets).
- sizing and attachment of side walls. The 1 mm thickness was chosen to provide sufficient stiffness in the case of a calorimeter mounted on top of the instrument grid. That thickness could be reduced for the calorimeter-inside-the-grid option, within limits imposed by manufacturing and assembly issues.
- material selection, sizing, tensioning, and attachment of tension members; kevlar fiber braided cables are being considered; other options are beryllium or graphite fiber rods.
- top and bottom panels: detailed design of close-out frames, facings, and selection of core material (graphite honeycomb, carbon or Beryllium foam) .
- printed circuit board layout, side-to-side flex connections, cabling.
- cabling to PIN diodes.

5.1.3 Simulations

- thermal design of calorimeter (equilibrium temperature as part of spacecraft, temperature distributions, etc.).
- detailed stress and deflection analysis of top and bottom panels..
- more detailed static response analysis (FEM, looking at stresses in particular).
- additional random vibration response calculations (deflections of side panels and PCB boards), including acoustic inputs.

6. Short Term Test Plan

Tests will be conducted to validate the unidirectional compression stack concept. The main issue is slippage of the CsI logs between the rubber sheets or inside their wrapping. A fixture is being built that will compress 1 to 3 logs between a pair of stiff plates and rubber layers. The fixture is shown in Fig. 18. The plates are pressed together with a series of 8 compression springs, allowing for a controllable and uniform pressure on the rubber and logs. After adjustment of the compression, side plates are added to prevent further changes in stack height and hold the top and bottom compression plates in relative position. The fixture will be mounted on the horizontal shake table of a large electromagnetic shaker. It will be vibrated in the horizontal direction, loading the rubber sheets in shear and imparting large interfacial friction loads. The log(s) will be instrumented with accelerometers. The table will be driven in sinusoidal motion at various frequencies and increasing amplitudes. Any slippage in the system will manifest itself with non-linearity in the response measurements.

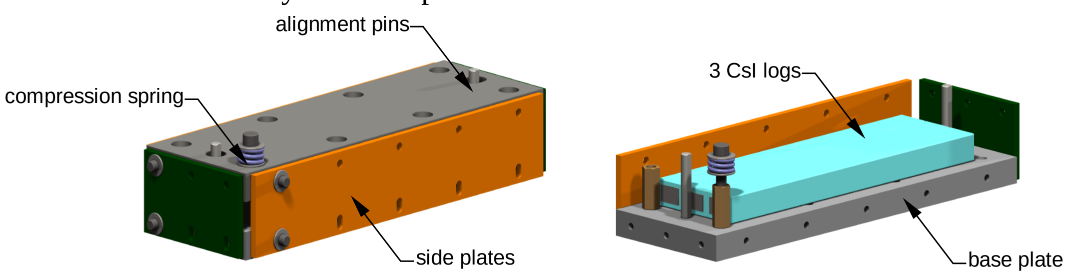

Figure 18: test fixture for compression cell concept; 3 logs are pressed side by side between two heavy plates and rubber layers; the fixture will be shaken to expose any slippage problems.

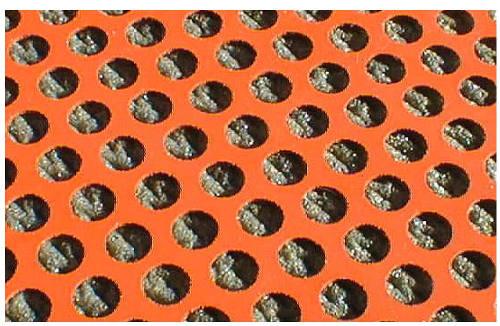

Figure 19: a first prototype sheet of 0.8 mm, 40 durometer silicone rubber, perforated as described in section 4.3.4.

The same fixture could also be used for long term creep measurements. The setup would be identical to that used for dynamic slippage tests, with the exception that the side plates are not mounted so that the springs maintain a constant pressure on the stack. The total height of the assembly will be monitored with digital indicators. Any sagging in the rubber or the CsI logs will be detected.

7. References

1. *Proposal for the Gamma Ray Large Area Space Telescope*, SLAC-R-522, Stanford Linear Accelerator Center, Stanford University, Stanford, CA, February 1998.
2. *GLAST Instrument Technology Development: Integrated Instrument Development and Demonstration*, Proposal, P. Michelson, P.I., Stanford University, Stanford, CA, March 5, 1998.
3. *Delta II Payload Planners Guide*, document # MDC H3224D, The Boeing Company, Huntington Beach, CA, available in electronic format http://www.boeing.com/defense-space/space/delta/delta2/guide.htm, April 1996.
4. *Shock and Vibration Handbook*, 3rd edition, C. M. Harris, editor, McGraw-Hill, 1987.
5. *General Environmental Specification for STS & ELV Payloads, Subsystems, and Components*, GEVS-SE Rev. A, System Reliability and Safety Office, Code 302, NASA/Goddard Space Flight Center, Greenbelt, MD, June 1996.